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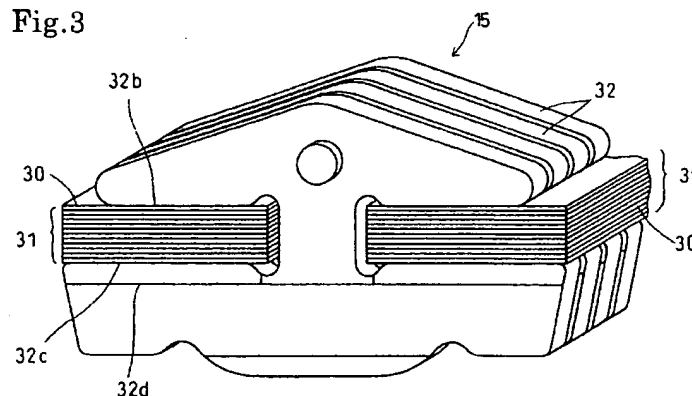
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(54) **Thin metal ring for metal belt type nonstep variable-speed transmission**

(57) Thin metal rings for a nonstep variable-speed transmission including a drive pulley and a driven pulley having variable effective diameters to change speed change ratio. The thin metal rings are layered to form layered ring structures, a plurality of blocks are arranged along and supported on the layered ring structures to form an endless metal belt, and the endless metal belt is extended between the drive and the driven pulley. A radially inner edge at the intersection of the outer side surface and the inner circumference of the innermost thin metal ring among the thin metal rings is rounded in a round edge of a radius R of curvature. The radius R of curvature is determined so that a maximum total round edge stress obtained by adding up a contact

stress induced in the round edge of the innermost thin metal ring in contact with the side surface of the pulley groove, a stress induced in the round edge by a tensile force exerted on the innermost thin metal ring, and a bending stress induced in the round edge of the innermost thin metal ring when the innermost thin metal ring is bent is equal to or smaller than a maximum inner circumference total stress obtained by adding up a contact stress induced in a part contiguous with the inner circumference of the innermost thin metal ring in contact with an edge of the block, a stress induced in the part contiguous with the inner circumference of the innermost thin metal ring and a bending stress induced in the part contiguous with the inner circumference of the innermost thin metal ring.

Fig.3



Description**BACKGROUND OF THE INVENTION**5 **Field of the Invention**

[0001] The present invention relates to a thin metal ring for a durable metal belt type nonstep variable-speed transmission.

10 **Description of the Related Art**

[0002] In a metal belt type nonstep variable-speed transmission including a drive pulley, a driven pulley and an endless metal belt formed by engaging blocks with a layered ring formed by radially superposing thin metal rings, and extended between the drive and the driven pulley, the endless metal belt is extended between the drive and the driven pulley in a necessary tension for power transmission. When the nonstep variable-speed transmission is in operation, the thin metal rings, which are annular in an unloaded state, are stretched linearly between the drive and the driven pulley and parts of each thin metal ring in engagement with the drive and driven pulley are curved in radii of curvature smaller than the radius of a circle in which the thin metal ring are formed in an unloaded state. Consequently, tensile stress and compressive stress are induced in the bent thin metal rings. A maximum tensile stress and a maximum compressive stress are induced in the outer surface farthest from the neutral plane of each thin metal ring and the inner surface farthest from the neutral plane of the same thin metal ring. Large stresses are induced locally in the opposite side edges at the intersections of the outer circumference and the side surfaces and at the intersections of the inner circumference and the side surfaces of each thin metal ring and those side edges are subject to fatigue failure.

[0003] To avoid shortening the life due to fatigue failure, a thin metal ring disclosed in JP-B No. Hei 6-6970 is shot-peened or rolled so that the thickness thereof decreases gradually from side portions toward the side edges thereof to a residual compressive stress in the side parts of the thin metal ring is greater than that in other parts of the same.

[0004] When the nonstep variable-speed transmission is in operation, tensile stress that varies according to the position on a running path is induced in addition to the tensile and compressive stress that are induced in the thin metal ring when the same is bent. If the side edges of the thin metal ring touch the pulley, a large stress is induced in the side edges. Nothing is taken into consideration in the prior art thin metal ring about the induction of such a stress in the side edges of the thin metal ring and, therefore, the durability of the prior art thin metal ring was not as high as expected.

SUMMARY OF THE INVENTION

[0005] Accordingly, it is an object of the present invention to provide an improved, sufficiently durable thin metal ring for a metal belt type nonstep variable-speed transmission.

[0006] According to a first aspect of the present invention, thin metal rings for a nonstep variable-speed transmission having a drive pulley and a driven pulley, the respective effective diameters of the drive and the driven pulley being variable to change speed change ratio, said thin metal rings being layered to form layered ring structures, a plurality of blocks being arranged along and supported on the layered ring structures to form an endless metal belt, and the endless metal belt being extended between the drive and the driven pulley; wherein an edge at an intersection of an outer side surface and an inner circumference of an innermost thin metal ring among the thin metal rings, that will come into contact with a side surface of a pulley groove of the drive pulley and a side surface of a pulley groove of the driven pulley is rounded in a round edge of a radius R of curvature, and the radius R of curvature is determined so that a maximum total round edge stress obtained by adding up a contact stress induced in the round edge of the innermost thin metal ring in contact with the side surface of the pulley groove, a stress induced in the round edge by a tensile force exerted on the innermost thin metal ring, and a bending stress induced in the round edge of the innermost thin metal ring when the innermost thin metal ring is bent is equal to or smaller than a maximum inner circumference total stress obtained by adding up a contact stress induced in a part contiguous with the inner circumference of the innermost thin metal ring in contact with an edge of the block, a stress induced in the part contiguous with the inner circumference of the innermost thin metal ring and a bending stress induced in the part contiguous with the inner circumference of the innermost thin metal ring. Thus, the induction of a large stress in the edge at the intersection of the outer side surface and the inner circumference of the innermost ring due to contact between the edge and the side surface of the pulley groove can be avoided and the failure of the innermost thin metal ring in a short period of use can be prevented. The innermost thin metal ring does not need to be worked by a rolling process or the like for work hardening. Consequently, the innermost thin metal ring can be fabricated by a simple process in a short processing time at a low cost.

[0007] According to a second aspect of the present invention, thin metal rings for a nonstep variable-speed trans-

mission having a drive pulley and a driven pulley, the respective effective diameters of the drive and the driven pulley being variable to change speed change ratio, said thin metal rings being layered to form layered ring structures, a plurality of blocks being arranged along and supported on the layered ring structures to form an endless metal belt, and the endless metal belt being extended between the drive and the driven pulley; wherein an edge at the intersection of an outer side surface and an inner circumference of an innermost thin metal ring among the thin metal rings, that will come into contact with a side surface of a pulley groove of the drive pulley and a side surface of a pulley groove of the driven pulley is rounded in a round edge of a radius R of curvature, and the radius R of curvature is determined so that a round edge stress difference between a maximum and a minimum total round edge stress obtained by adding up a contact stress induced in the round edge of the innermost thin metal ring in contact with the side surface of the pulley groove, a stress induced in the round edge by a tensile force exerted on the innermost thin metal ring, and a bending stress induced in the round edge of the innermost thin metal ring when the innermost thin metal ring is bent is smaller than an inner circumference stress difference between a maximum and a minimum inner circumference total stress obtained by adding up a contact stress induced in a part contiguous with the inner circumference of the innermost thin metal ring in contact with an edge of the block, a stress induced in the part contiguous with the inner circumference of the innermost thin metal ring and a bending stress induced in the part contiguous with the inner circumference of the innermost thin metal ring when the innermost thin metal ring is bent. Thus, the induction of a large stress in the edge at the intersection of the outer side surface and the inner circumference of the innermost ring due to contact between the edge and the side surface of the pulley groove can be avoided and the failure of the innermost thin metal ring in a short period of use can be prevented.

[0008] According to a third aspect of the present invention, thin metal rings for a nonstep variable-speed transmission having a drive pulley and a driven pulley, the respective effective diameters of the drive and the driven pulley being variable to change speed change ratio, said thin metal rings being layered to form layered ring structures, a plurality of blocks being arranged along and supported on the layered ring structures to form an endless metal belt, and the endless metal belt being extended between the drive and the driven pulley; wherein the edge at the intersection of the outer side surface and the inner circumference of the innermost thin metal ring, that will come into contact with the side surface of the pulley groove of the drive pulley and the side surface of the pulley groove of the driven pulley is rounded in a round edge of a radius R of curvature, and the radius R of curvature is determined so that a round edge fatigue stress determined from a maximum and a minimum total round edge stress obtained by adding up a contact stress induced in the round edge of the innermost thin metal ring in contact with the side surface of the pulley groove, a stress induced in the round edge by a tensile force exerted on the innermost thin metal ring, and a bending stress induced in the round edge of the innermost thin metal ring when the innermost thin metal ring is bent is equal to or smaller than an inner circumference fatigue stress determined from a maximum and a minimum inner circumference total stress obtained by adding up a contact stress induced in a part contiguous with the inner circumference of the innermost thin metal ring in contact with an edge of the block, a stress induced in the part contiguous with the inner circumference of the innermost thin metal ring and a bending stress induced in the part contiguous with the inner circumference of the innermost thin metal ring. Thus, the fatigue failure of the round edge of the innermost thin metal ring can be avoided and the life of the innermost thin metal ring can be extended.

[0009] According to a fourth aspect of the present invention, thin metal rings for a nonstep variable-speed transmission having a drive pulley and a driven pulley, the respective effective diameters of the drive and the driven pulley being variable to change speed change ratio, said thin metal rings being layered to form layered ring structures, a plurality of blocks being arranged along and supported on the layered ring structures to form an endless metal belt, and the endless metal belt being extended between the drive and the driven pulley; wherein the edge at the intersection of the outer side surface and the inner circumference of the innermost thin metal ring among the thin metal rings, that will come into contact with a side surface of the pulley groove of the drive pulley and a side surface of the pulley groove of the driven pulley is rounded in a round edge of a radius R of curvature, and the radius R of curvature is determined so that a contact part corrected stress difference ($\sigma_{a*HP} = \sigma_{aHP} + \sigma_{mHP}/3$) calculated by adding a round edge stress difference σ_{aHP} between a maximum and a minimum total round edge stress obtained by adding up a contact stress induced in the round edge of the innermost thin metal ring in contact with the side surface of the pulley groove, a stress induced in the round edge by a tensile force exerted on the innermost thin metal ring, and a bending stress induced in the round edge of the innermost thin metal ring when the innermost thin metal ring is bent, and 1/3 of a mean round edge stress (σ_{mHP}) equal to the mean of the maximum and the minimum total round edge stress is equal to or smaller than an inner circumference corrected stress difference ($\sigma_{a*} = \sigma_a + \sigma_m/3$) calculated by adding an inner circumference stress difference (σ_a) between a maximum and a minimum inner circumference total stress obtained by adding up a contact stress induced in a part contiguous with the inner circumference of the innermost thin metal ring in contact with an edge of the block, a stress induced in the part contiguous with the inner circumference of the innermost thin metal ring and a bending stress induced in the part contiguous with the inner circumference of the innermost thin metal ring when the innermost thin metal ring is bent, and 1/3 of the mean ($\sigma_m/3$) of the maximum and the minimum inner circumference total stress ($\sigma_{a*HP} \leq \sigma_{a*}$). Thus, the failure of the round edge of the innermost thin metal ring that will come

into contact with the side surface of the pulley groove due to fatigue stress can be prevented and the durability and reliability of the innermost thin metal ring can be greatly improved.

[0010] According to a fifth aspect of the present invention, thin metal rings for a nonstep variable-speed transmission having a drive pulley and a driven pulley, the respective effective diameters of the drive and the driven pulley being variable to change speed change ratio, said thin metal rings being layered to form layered ring structures, a plurality of blocks being arranged along and supported on the layered ring structures to form an endless metal belt, and the endless metal belt being extended between the drive and the driven pulley; wherein an edge at the intersection of the outer side surface and the inner circumference of the innermost thin metal ring among the thin metal rings, that will come into contact with a side of a pulley groove of the drive pulley and a side of a pulley groove of the driven pulley is rounded in a round edge of a radius R of curvature having the shape of a quarter of a cylinder, and the radius R is determined so that a contact part corrected stress difference calculated by adding a round edge stress difference between a maximum and a minimum total round edge stress obtained by adding up a contact stress induced in the round edge of the innermost thin metal ring in contact with the side surface of the pulley groove, a stress induced in the round edge by a tensile force exerted on the innermost thin metal ring, and a bending stress induced in the round edge of the innermost thin metal ring when the innermost thin metal ring is bent, and $1/3$ of a mean round edge stress equal to the mean of the maximum and the minimum total round edge stress is equal to or smaller than an inner circumference corrected stress difference calculated by adding an inner circumference stress difference between a maximum and a minimum inner circumference total stress obtained by adding up a contact stress induced in the part contiguous with the inner circumference of the innermost thin metal ring in contact with an edge of the block, a stress induced in the part contiguous with the inner circumference of the innermost thin metal ring and a bending stress induced in the part contiguous with the inner circumference of the innermost thin metal ring when the innermost thin metal ring is bent, and $1/3$ of the mean of the maximum and the minimum inner circumference total stress. Thus, the failure of the round edge of the innermost thin metal ring that will come into contact with the side surface of the pulley groove due to fatigue stress can be prevented and the durability and reliability of the innermost thin metal ring can be greatly improved. Thus, the height of a point in contact with the side surface of the pulley groove on the round edge of the innermost thin metal ring from the inner circumference of the same changes scarcely even if the angular relation between the inner circumference of the innermost thin metal ring and the side surface of the pulley groove changes. Consequently, change in the contact stress induced in the part of the round edge in contact with the side surface of the pulley groove can be avoided.

[0011] According to a sixth aspect of the present invention, thin metal rings for a nonstep variable-speed transmission having a drive pulley and a driven pulley, the respective effective diameters of the drive and the driven pulley being variable to change speed change ratio, said thin metal rings being layered to form layered ring structures, a plurality of blocks being arranged along and supported on the layered ring structures to form an endless metal belt, and the endless metal belt being extended between the drive and the driven pulley; wherein an edge at the intersection of the outer side surface and the inner circumference of the innermost thin metal ring among the thin metal rings, that will come into contact with a side of the pulley groove of the drive pulley and a side of the pulley groove of the driven pulley is chamfered in a bevel surface at an angle greater than the groove angle (α) of the pulley groove and the bevel surface is merged smoothly into the outer side surface of the innermost thin metal ring by a round edge of a radius R of curvature that comes into contact with the side surface of the pulley groove, and the radius R is determined so that a contact part corrected stress difference calculated by adding a round edge stress difference between a maximum and a minimum total round edge stress obtained by adding up a contact stress induced in the round edge of the innermost thin metal ring in contact with the side surface of the pulley groove, a stress induced in the round edge by a tensile force exerted on the innermost thin metal ring, and a bending stress induced in the round edge of the innermost thin metal ring when the innermost thin metal ring is bent, and $1/3$ of a mean round edge stress equal to the mean of the maximum and the minimum total round edge stress is equal to or smaller than an inner circumference corrected stress difference calculated by adding an inner circumference stress difference between a maximum and a minimum inner circumference total stress obtained by adding up a contact stress induced in the part contiguous with the inner circumference of the innermost thin metal ring in contact with an edge of the block, a stress induced in the part contiguous with the inner circumference of the innermost thin metal ring and a bending stress induced in the part contiguous with the inner circumference of the innermost thin metal ring when the innermost thin metal ring is bent, and $1/3$ of the mean of the maximum and the minimum inner circumference total stress. Thus, stress that causes the fatigue failure of the round edge of the innermost thin metal ring when the endless metal belt is extended between the drive and the driven pulley can be reduced and the durability of the innermost thin metal ring can be improved because round edge that comes into contact with the side surface of the pulley groove is spaced as far as possible from the inner circumference of the innermost thin metal ring toward the outer circumference of the same.

[0012] According to a seventh aspect of the present invention, thin metal rings for a nonstep variable-speed transmission having a drive pulley and a driven pulley, the respective effective diameters of the drive and the driven pulley being variable to change speed change ratio, said thin metal rings being layered to form layered ring structures, a

plurality of blocks being arranged along and supported on the layered ring structures to form an endless metal belt, and the endless metal belt being extended between the drive and the driven pulley; wherein a side surface of each thin metal ring has a middle flat part, an edge at the intersection of the side surface and the inner circumference of the thin metal ring is rounded in a radially inner round edge of a radius R_1 of curvature and an edge at the intersection of the side surface and the outer circumference of the thin metal ring is rounded in a radially outer round edge of a radius R_2 of curvature different from the radius R_1 . When the round edge that comes into contact with the side surface of the pulley groove is formed in the greater one of the radii R_1 and R_2 , the stress induced in the thin metal ring can be reduced, fatigue failure due to contact stress can be avoided and the durability of the thin metal ring can be improved regardless of the distance between a part of the innermost thin metal ring that come into contact with the side surface of the pulley groove and the circumferential of the same regardless of changes in the inclination of the sides of the pulley grooves of the pulleys, and the inclination and shape of the side surface of the thin metal ring.

[0013] Preferably, the radius R_1 of curvature of the radially inner round edge of the thin metal ring meets a condition: $R_1/t \geq 2/9$, where t is the thickness of the thin metal ring, when the groove angle (α) of the pulley groove is in the range of 6° to 11° . Thus, a stress determined by a round edge stress difference between a maximum and a minimum stress induced in the round edge of the innermost thin metal ring when the round edge comes into contact with the side surface of the pulley groove of the drive or the driven pulley, and the mean of the maximum and the minimum can be limited to a value below a stress determined by the stress difference between a maximum and a minimum combined stress obtained by adding a tensile stress induced in the thin metal ring by a tension applied thereto, and a tensile stress and a compressive stress induced in the thin metal ring when the thin metal ring is bent around the drive or the driven pulley, and the mean of the maximum and the minimum combined stress. Consequently, the fatigue failure of the round edge of the innermost thin metal ring can be avoided and the durability of the endless metal belt can be improved.

[0014] Preferably, the radius R_1 of curvature of the radially inner round edge of each thin metal ring is greater than the radius R_2 of curvature of the radially outer round edge of the same thin metal ring. Thus, the stress induced in the inner side edge of the thin metal ring in which a large stress is liable to be induced can be limited to a level substantially equal to or lower than that of the stress induced in the outer side edge, so that the durability of the endless metal belt can be enhanced.

[0015] Preferably the respective radii R_1' and R_2' of curvature of the radially inner and the radially outer round edge of the innermost thin metal ring are equal to or greater than the respective radii R_1 and R_2 of curvature of the radially inner and the radially outer round edge of the thin metal rings other than the innermost thin metal ring, respectively. Thus, the stresses induced in the inner and the outer round edges of the innermost thin metal ring can be limited to levels equal to or below those of the stresses induced in the inner and the outer round edges of the other thin metal rings, so that the fatigue failure of the inner and the outer round edge of the innermost thin metal ring that occurs before that of the other thin metal rings can be prevented and the durability of the endless metal belt can be improved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] The above and other objects, features and advantages of the present invention will become more apparent from the following description taken in connection with the accompanying drawings, in which:

Fig. 1 is a diagrammatic view of a metal belt type nonstep variable-speed transmission provided with an endless metal belt including thin metal rings in a preferred embodiment according to the present invention;

Fig. 2 is a schematic side elevation of a wrapping connector driving mechanism shown in Fig. 1p

Fig. 3 is a fragmentary perspective view of an endless metal belt included in the wrapping connector driving mechanism shown in Fig. 2;

Fig. 4 is a front elevation of a metal block;

Fig. 5 is a longitudinal sectional view taken on line V-V in Fig. 4;

Fig. 6 is a longitudinal sectional view taken on line VI-VI in Fig. 4;

Fig. 7 is a diagrammatic view of assistance in explaining tensile force that acts on an innermost thin metal ring included in the endless metal belt shown in Fig. 3;

Fig. 8 is a graph of assistance in explaining the relation between tensile forces and friction coefficients;

Fig. 9 is graph showing the distribution of internal stress in a middle part with respect to thickness of the innermost thin metal ring;

Fig. 10 is graph showing the distribution of internal stress in the outer circumference of the innermost thin metal ring;

Fig. 11 is diagram showing the distribution of internal stress in the outer circumference of the innermost thin metal ring;

Fig. 12 is a fragmentary longitudinal sectional view of the endless metal belt;

Fig. 13 is an enlarged, fragmentary, cross-sectional view of the endless metal belt;

Fig. 14 is an enlarged, fragmentary, cross-sectional view of a part of Fig. 13;

Fig. 15 is a diagram showing the distribution of contact stress in a state where the inner side edge of the innermost thin metal ring is in contact with the side surface of a ring groove;

Fig. 16 is a graph showing the corrected stress differences relating to the interior and an end of the innermost thin metal ring;

Fig. 17 is an enlarged, fragmentary, cross-sectional view of the innermost thin metal ring included in thin metal rings in a second embodiment according to the present invention;

Fig. 18 is an enlarged, fragmentary, cross-sectional view of the innermost thin metal ring included in thin metal rings in a third embodiment according to the present invention;

Fig. 19 is a table tabulating stresses that are induced in the innermost thin metal ring;

Fig. 20 is a table tabulating stresses that are induced in the innermost thin metal ring; and

Fig. 21 is a graph showing the relation between the height of the round edge (30_{1d}) from the inner circumference (30_a) of the innermost thin metal ring and the radius (R) of curvature of the round edge (30_{1d}) for determining the radius R of curvature of the round edge that come into contact with the side surface of the pulley groove for the height h to make corrected internal stress difference (σ_a) and contact part corrected stress difference ($\sigma_a \cdot HP$) are equal.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0017] A thin metal ring in a first embodiment according to the present invention will be described with reference to Figs. 1 to 6. Referring to Fig. 1, an input shaft 3 is connected through a damper 2 to an internal combustion engine E. The input shaft is connected through a starter clutch 4 to a drive shaft 5 included in a metal belt type nonstep variable-speed transmission T. A drive pulley 6 mounted on the drive shaft 5 has a stationary part 7 formed integrally with the drive shaft 5 and a movable part 8 mounted on the drive shaft 5 so as to be movable toward and away from the stationary part 7. The movable part 8 is biased toward the fixed part 7 by fluid pressure applied to an oil chamber 9. A driven shaft 10 is supported in parallel to the drive shaft 5 and a driven pulley 11 is mounted on the driven shaft 10. The driven pulley 11 has a stationary part 12 formed integrally with the driven shaft 10 and a movable part 13 mounted on the driven shaft 10 so as to be movable toward and away from the stationary part 12. The movable part 13 is biased toward the stationary part 12 by fluid pressure applied to an oil chamber 14.

[0018] Referring to Figs. 2 and 3, an endless metal belt 15 is formed by inserting a pair of layered ring structures 31 in slots 32a formed in opposite side parts of metal blocks 32. The endless metal belt 15 is extended between the drive pulley 6 and the driven pulley 11. Each layered ring structure 31 is formed by closely superposing twelve thin metal rings 30 of about 660 mm in circumference, about 9.2 mm in width and about 0.18 mm in thickness. As shown in Fig. 13, the inner side edges at the intersections of the opposite side surfaces 30c and the inner circumference 30a of each thin metal ring 30 are ground in inner round edges 30d of a shape substantially resembling a quarter of a circular cylinder, and the outer side edges at the intersections of the opposite side surfaces 30c and the outer circumference 30b of each thin metal ring 30 are ground in outer round edges 30e of a shape substantially resembling a quarter of a circular cylinder. The radius R_1 of curvature of the inner round edge 30_{1d} of the innermost thin metal ring 30₁ is greater than the radius R_2 of curvature of the outer round edge 30_{1e} of the same.

[0019] A forward drive gear 16 and a reverse drive gear 17 are mounted on the driven shaft 10 so as to be rotatable relative to each other. The forward drive gear 16 and the reverse drive gear 17 are engaged with and disengaged from the driven shaft 10 selectively by a selector 18. An output shaft 19 is extended in parallel to the driven shaft 10. A forward driven gear 20 and a reverse driven gear 22 are formed integrally with the output shaft 19. The output shaft 19 is driven for forward rotation through the forward driven gear 20 by the forward drive gear 16. The output shaft 19 is driven for reverse rotation through a reverse idle gear 21 and the reverse driven gear 22 by the reverse drive gear 17. A final drive gear 23 is formed integrally with the output shaft 19, and a final driven gear 24 engaged with the final drive gear 23 is combined with a differential gear 25. The differential gear 25 is connected to right and left wheels W by right and left axles 26. The driving force of the output shaft 19 is transmitted differentially through the final drive gear 23, the final driven gear 24, the differential gear 25 and the axles 26 to the right and the left wheel W.

[0020] The respective oil chambers 9 and 14 of the movable parts 8 and 13 are connected to a hydraulic control unit U_2 controlled by an electronic control unit U_1 . When setting the metal belt type nonstep variable-speed transmission T to LOW, the electronic control unit U_1 gives a control signal to the hydraulic control unit U_2 to increase the fluid pressure in the oil chamber 14 of the driven pulley 11 and to decrease the fluid pressure in the oil chamber 9 of the drive pulley 6. Consequently, the effective diameter D_{DN} of the driven pulley 11 increases continuously and the effective diameter D_{DR} decreases continuously, so that the speed change ratio of the metal belt type nonstep variable-speed transmission T varies continuously to LOW. When setting the metal belt type nonstep variable-speed transmission T to OD, the electronic control unit U_1 gives a control signal to the hydraulic control unit U_2 to decrease the fluid pressure in the oil chamber 14 of the driven pulley 11 and to increase the fluid pressure in the oil chamber 9 of the drive pulley

6. Consequently, the effective diameter D_{DN} of the driven pulley 11 decreases continuously and the effective diameter D_{DR} increases continuously, so that the speed change ratio of the metal belt type nonstep variable-speed transmission T varies continuously to OD.

[0021] Stresses that will be induced in the thin metal ring 30 will be explained. When the layered ring structures 31 are extended between the drive pulley 6 and the driven pulley 11 and the drive pulley 6 is driven for clockwise rotation as shown in Fig. 2, a tensile stress T_1 is induced in one straight side of each layered ring structure 31 extending between the drive pulley 6 and the driven pulley 11 and a tensile stress T_2 is induced in the other straight side of the layered ring structure 31. The tensile stresses T_1 and T_2 are measured by a method mentioned in JP-A No. Hei 10-89429.

[0022] When the endless metal belt 15 formed by inserting the pair of layered ring structures 31 in the slots 32a of the metal blocks 32 is extended between the drive pulley 6 and the driven pulley 11, a tensile force difference ΔT_1 acts on the innermost thin metal ring 30₁.

$$\Delta T_1 = \{n(\xi - 1) + 1\} \Delta T_{all} / n\xi$$

where $\Delta T_{all} = (T_1 - T_2)/2$, ξ is friction coefficient ratio (μ_{SSM}/μ_{SS}), μ_{SSM} is the friction coefficient between the metal block 32 and the thin metal ring 30, μ_{SS} is the friction coefficient between the thin metal rings 30 and n is the number of the layered thin metal rings 30.

[0023] Referring to Fig. 7 showing a simple model of an endless metal belt having three thin metal rings, tensile force differences ΔT that contribute to tension change are:

$$\Delta T_3 = F_3 = \mu_{SS} N$$

$$\Delta T_2 = F_2 - F_3 = \mu_{SS} N$$

$$\Delta T_1 = F_1 - F_2 = 3\mu_{SSM} N - 2\mu_{SS} N$$

[0024] Thus, ΔT_1 is different from ΔT_2 and ΔT_3 .

$$\Delta T_1 / \Delta T_2 = (3\mu_{SSM} N - 2\mu_{SS} N) / \mu_{SS} N = (3\mu_{SSM} - 2\mu_{SS}) / \mu_{SS}$$

[0025] Therefore, when the number of the thin metal rings is n ,

$$\begin{aligned} \Delta T_1 / \Delta T_2 &= \{n\mu_{SSM} N - (n - 1)\mu_{SS} N\} / \mu_{SS} N = \{n\mu_{SSM} - (n - 1)\mu_{SS}\} / \mu_{SS} \\ &= n\xi - (n - 1) = n(\xi - 1) + 1 \quad \dots\dots\dots (1) \end{aligned}$$

[0026] The tensile force difference ΔT_{all} in the entire layered ring structure 31 is:

$$\begin{aligned} \Delta T_{all} &= \Delta T_1 + \Delta T_2 + \dots + \Delta T_n = (n - 1)\Delta T_2 + \Delta T_1 \\ &= (n - 1)\Delta T_2 + \{n(\xi - 1) + 1\}\Delta T_2 = n\xi\Delta T_2 \end{aligned}$$

[0027] Therefore,

$$\Delta T_2 = 1/n\xi\Delta T_{all} \quad (2)$$

[0028] By substituting Expression (2) into Expression (1),

$$\Delta T_1 = \{n(\xi - 1) + 1\}/n\xi \Delta T_{all} \quad (3)$$

[0029] Fig. 8 shows the relation between $\Delta T_1/\Delta T_{all}$ and μ_{SSM}/μ_{SS} when $n = 12$ calculated by using Expression (3)

[0030] The friction coefficient μ_{SSM} between the metal blocks 32 and the thin metal ring 30 and the friction coefficient μ_{SS} between the thin metal rings 30 determined through experiments were about 0.1 and about 0.05, respectively. Thus, $\mu_{SSM}/\mu_{SS} = \xi = 2.0$.

[0031] The value of ΔT_1 was calculated by using these values and Expression (3).

$$\Delta T_1/\Delta T_{all} = (12 + 1)/12 \times 2 = 13/24 \approx 0.54$$

[0032] From Fig. 8,

$$\Delta T_1/\Delta T_{all} \approx 0.5$$

[0033] Thus, about 50% of the tensile force difference ΔT_{all} in the one layered ring structure 31 acts on the innermost thin metal ring 30₁. The mean tensile force $T_1 + T_2$ in the innermost thin metal ring 30₁ is determined. From the mean tensile force difference $T_1 - T_2$ and the mean tensile force $T_1 + T_2$, the maximum tensile stress $\sigma_{TH} = T_1/2 \times 12 \times A \times t$ in the innermost thin metal ring 30₁ moving from the drive pulley 6 toward the driven pulley 11 and the minimum tensile stress $\sigma_{TL} = T_2/2 \times 12 \times A \times t$ in the innermost thin metal ring 30₁ moving from the driven pulley 11 toward the drive pulley 6, where A is the width and t is the thickness of the thin metal ring 30, are determined.

[0034] Fig. 9 is graph showing the distribution of tensile stress σ_T in a middle part with respect to thickness of the innermost thin metal ring 30₁, in which the length of the innermost thin metal ring 30₁ is measured on the horizontal axis and the stress in the middle part of the innermost thin metal ring 30₁ is measured on the vertical axis (tensile stress and compressive stress are measured upward and downward from the horizontal axis, respectively). In the graph shown in Fig. 9, the difference between the maximum and the minimum stress is $2\sigma_a$, where σ_a is stress difference, and the mean of the maximum and the minimum stress is the mean stress σ_m .

[0035] The thin metal rings 30 are in a circle of a radius R_0 when the same are not extended between the drive pulley 6 and the driven pulley 11 and are in an unloaded state. When the thin metal rings 30 are extended between the drive pulley 6 and the driven pulley 11, parts of the innermost thin metal ring 30₁ wound around the drive pulley 6 and the driven pulley 11 are curved in arcs of circles of radii R_{RD} and R_{DN} , respectively, and parts of the innermost thin metal ring 30₁ extending between the drive pulley 6 and the driven pulley 11 are stretched straight. Consequently, bending stresses $\sigma_{VDR} = Et\{(1/R_{DR}) - (1/R_0)\}$ and $\sigma_{VDN} = Et\{(1/R_{DN}) - (1/R_0)\}$ (plus sign indicates tensile stress and minus sign indicates compressive stress) are induced in a part contiguous with the outer circumference of the innermost thin metal belt 30₁ wound around the drive pulley 6 and a part contiguous with the inner circumference of the innermost thin metal ring 30₁ wound around the driven pulley 11, respectively. A bending stress $\sigma_{V1} = Et(1/R_0)$ is induced in a part contiguous with the outer circumference of the innermost thin metal ring 30₁ extending between the drive pulley 6 and the driven pulley 11.

[0036] Fig. 10 shows the variation of the stress induced in the part contiguous with the outer circumference of the innermost thin metal ring 30₁ along the length of the innermost thin metal ring 30₁. In the graph shown in Fig. 10, dotted lines indicates the sum of addition of σ_T and σ_{VDR} in the part wound around the drive pulley 6, the sum of addition of σ_T and σ_{VDN} in the part wound around the driven pulley 11, the remainder of subtraction of σ_{V1} from σ_{TH} in the straight part, and the remainder of subtraction of σ_{V1} from σ_{TL} in the straight part, respectively.

[0037] Fig. 11 shows the variation of the stress induced in the part contiguous with the inner circumference of the innermost thin metal ring 30₁ along the length of the innermost thin metal ring 30₁. In the graph shown in Fig. 11, dotted lines indicates the remainder of subtraction of σ_{VDR} (compressive stress) from σ_T in the part wound around the drive pulley 6, the remainder of subtraction of σ_{VDN} (compressive stress) from σ_T in the part wound around the driven pulley 11, the sum of addition of σ_{V1} and σ_{TH} in the straight part, and the sum of addition of σ_{V1} and σ_{TL} in the straight part, respectively.

[0038] As shown in Fig. 11, the stress σ_{VDN} in a part X (Fig. 2) of the innermost thin metal ring 30₁ leaving the driven pulley 11 drops sharply because the rear edge 32c of the inner side surface 32b of the slot 32a of the metal block 32 bites the inner circumference 30_{1a} of the innermost thin metal ring 30₁ as shown in Fig. 12 and a large, local contact stress is induced.

[0039] A description will be made of contact stress that will be induced in a contact part 30_{1f} of the inner round edge 30_{1d} when the inner round edge 30_{1d} comes into contact with a side surface 27 of the pulley groove. When the inner

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round edge 30_{1d} having a radius R₁ of curvature of the innermost thin metal ring 30₁ comes into contact with the side surface 27 of the pulley groove as shown in Fig. 14, the contact part 30_{1f} is in contact with the side surface 27 of the pulley groove 27 at a distance: $h = R_1(1 - \sin \alpha)$ from the inner circumference 30_{1a}. A contact stress induced in a part around the contact part 30_{1f} is expressed by the following expression called Hertz formula.

$$\sigma_{HP} = [Q/\pi \cdot 1 \cdot R_1 \{ (1 - V_1^2)/E_1 + (1 - V_2^2)/E_2 \}]^{1/2} \quad (4)$$

where V₁ is the Poisson ratio of the thin metal ring 30, V₂ is the Poisson ratio of the drive pulley 6 and the driven pulley 11, and E₁ and E₂ are elastic moduli of the thin metal ring 30, and the pulleys 6 and 11. Supposing V₁ = V₂ = 0.3 and E₁ = E₂,

$$\sigma_{HP} = \{Q \cdot E / 2 \cdot \pi \cdot 1 \cdot R_1 (1 - V_2^2)\}^{1/2} \quad (5)$$

[0040] Fig. 11 shows the variation of the stress induced in the part contiguous with the inner circumference 30_{1a} of the innermost thin metal ring 30₁ along the length of the innermost thin metal ring 30₁. Fig. 15 shows the variation of the stress induced in a part of the innermost thin metal ring 30₁ at a distance h from the inner circumference 30_{1a} toward the outer circumference 30_{1b} along the length of the innermost thin metal ring 30₁.

[0041] Generally, the fatigue strength of a metal is related with the stress difference σ_a between a maximum stress and a minimum stress, and the mean stress σ_m . The fatigue strength of a steel is dependent on corrected internal stress difference σ_{a^*} expressed by:

$$\sigma_{a^*} = \sigma_a + \sigma_m/3 \quad (6)$$

[0042] Corrected contact stress difference σ_{a^*HP} in the contact part of the inner round edge 30_{1d} of the innermost thin metal ring 30₁ in contact with the side surface 27 of the pulley groove is expressed by:

$$\sigma_{a^*HP} = \sigma_{aHP} + \sigma_{mHP}/3 \quad (7)$$

[0043] Table 1 shown in Fig. 19 calculated values of the corrected internal stress difference σ_{a^*} and contact part corrected stress difference σ_{a^*HP} . In Table 1, values for the radius R₁ of curvature of the inner round edge 30_{1d} of the innermost thin metal ring 30₁ are 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08 and 0.09 mm, and the height h of the contact part in contact with the side surface 27 of the pulley groove from the inner circumference of the innermost thin metal ring 30₁ is calculated by using: $h = R_1(1 - \sin \sigma)$. Pulley Hertz compressive stresses $\sigma_{hp(DR)}$ and $\sigma_{hp(DN)}$ at the height h are calculated by using Expression (5). Internal stresses (the stress difference σ_a , the mean stress σ_m and the corrected stress difference σ_{a^*}) in a part at the height h in the innermost thin metal ring 30₁ are determined by methods similar to those mentioned above.

[0044] The internal stresses in the innermost thin metal ring 30₁ and the pulley Hertz compressive stresses are combined to determine pulley contact stresses (the pulley contact stress difference σ_{aHP} , the mean pulley contact stress σ_{mHP} and the contact part corrected stress difference σ_{a^*HP}) in the contact part of the innermost thin metal ring 30₁ in contact with the side surface 27 of the pulley groove as shown in Fig. 15.

[0045] Fig. 16 shows values of the corrected internal stress difference σ_{a^*} and the contact part corrected stress difference σ_{a^*HP} for different values of the height h, in which the corrected internal stress difference σ_{a^*} and the contact part corrected stress difference σ_{a^*HP} are measured on the vertical axis and the height h is measured on the horizontal axis. As obvious from Fig. 16, the contact part corrected stress difference σ_{a^*HP} is greater than the corrected internal stress difference σ_{a^*} in the part contiguous with the inner circumference 30_{1a} in which the corrected internal stress difference σ_{a^*} is the greatest when the radius R₁ of curvature of the inner round edge 30_{1d} is one of 0.01, 0.02 and 0.03 mm. When the radius R₁ is 0.04 mm or above, the contact part corrected stress difference σ_{a^*HP} is smaller than the corrected internal stress difference σ_{a^*} in the part contiguous with the inner circumference 30_{1a}. The fatigue failure of the innermost thin metal ring 30₁ that starts from the inner round edge 30_{1d} of the innermost thin metal ring 30₁ that comes into contact with the side surface 27 of the pulley groove can be prevented by forming the inner round edge 30_{1d} of the innermost thin metal ring 30₁ in a radius R of curvature of 0.04 mm or above.

[0046] The aforesaid values are calculated on an assumption that the inner round edge 30_{1d} of a part of the innermost thin metal ring 30₁ wound round the pulley is entirely in contact with the side surface 27 of the pulley groove. However,

if the inner round edge 30_{1d} of a part of the innermost thin metal ring 30₁ wound round the pulley is in local contact with the side surface 27 of the pulley groove, the contact part corrected stress difference σ_{a+HP} increases. Therefore, if the radius R_1 of curvature of the inner round edge 30_{1d} is 0.03 or below, the fatigue failure of the inner round edge 30_{1d} of the innermost thin metal ring 30₁ is liable to start earlier than that of the inner circumference 30_{1a} of the same.

[0047] Thus, in this embodiment, the start of fatigue failure from the inner round edge 30_{1d} of the innermost thin metal ring 30₁ can be avoided when the radius R_1 of curvature of the inner round edge 30_{1d} of the innermost thin metal ring 30₁ is 0.04 mm or above and the ratio $R_1/t = 2/9$.

[0048] The radius R_2 of curvature of the outer round edge 30_{1e} of the innermost thin metal ring 30₁ is smaller than the radius R_1 of curvature of the inner round edge 30_{1d} of the same as shown in Fig. 13. Therefore, time necessary for finishing the outer round edge 30_{1e} of the innermost thin metal ring 30₁ by grinding can be reduced and the innermost thin metal ring 30₁ can be easily fabricated.

[0049] In this embodiment, the radially inner and the radially outer edge of the thin metal ring 30, particularly, the innermost thin metal ring 30₁, are mechanically ground to form the inner and the outer round edge. As shown in Fig. 17, the radially inner and the radially outer edge of the thin metal ring 30 may be chamfered in bevel surfaces and the bevel surfaces may be finished by barrel finishing so that a part of the bevel surface that will come into contact with the side surface 27 of the pulley groove is rounded in a round edge of a radius R_4 of about 0.04 mm. The thin metal ring 30 thus finished by barrel finishing has a fatigue strength similar to that of the innermost thin metal ring 30₁ in the aforesaid embodiment. Since the radially inner and the radially outer edge of the thin metal ring 30 are chamfered, time for barrel finishing can be greatly reduced.

[0050] Since the radially inner and the radially outer edge of the thin metal ring 30 are chamfered, the height h of the part of the round edge that will come into contact with the side surface 27 of the pulley groove from the inner circumference can be easily increased. Therefore, the radius R_4 of curvature of the part that will come into contact with the side surface 27 of the pulley groove may be smaller than the radius R_1 , so that time for barrel finishing can be further reduced.

[0051] Only the edge at the intersection of the inner circumference 30_{1a} and the side surface 30_{1c} of the innermost thin metal ring 30₁ may be chamfered in a large bevel surface as shown in Fig. 18 to increase the height h of the round edge 30_{1d} that will come into contact with the side surface 27 of the pulley groove from the inner circumference 30_{1a}, which is effective in further extending the fatigue life of the round edge 30_{1d}.

[0052] Table 2 shown in Fig. 20 tabulates values of the corrected internal stress difference σ_a and the contact part corrected stress difference σ_{a+HP} in the innermost thin metal ring 30₁ for different values of the height h . Fig. 21 is a graph for determining the radius R of curvature of the round edge that come into contact with the side surface 27 of the pulley groove for the height h to make $\sigma_{a+HP} = \sigma_a$. When the height h of the contact part, i.e., the round edge 30_{1d}, from the inner circumference 30_{1a} is increased, the radius R of curvature of the round edge 30_{1d} may be reduced, which simplifies a process for forming the round edge 30_{1d} and reduces the contact part corrected difference σ_{a+HP} in the contact part, i.e., the round edge 30_{1d}.

[0053] Although the invention has been described in its preferred embodiments with a certain degree of particularity, obviously many changes and variations are possible therein. It is therefore to be understood that the present invention may be practiced otherwise than as specifically described herein without departing from the scope and spirit thereof.

[0054] Thin metal rings for a nonstep variable-speed transmission including a drive pulley and a driven pulley having variable effective diameters to change speed change ratio. The thin metal rings are layered to form layered ring structures, a plurality of blocks are arranged along and supported on the layered ring structures to form an endless metal belt, and the endless metal belt is extended between the drive and the driven pulley. A radially inner edge at the intersection of the outer side surface and the inner circumference of the innermost thin metal ring among the thin metal rings is rounded in a round edge of a radius R of curvature. The radius R of curvature is determined so that a maximum total round edge stress obtained by adding up a contact stress induced in the round edge of the innermost thin metal ring in contact with the side surface of the pulley groove, a stress induced in the round edge by a tensile force exerted on the innermost thin metal ring, and a bending stress induced in the round edge of the innermost thin metal ring when the innermost thin metal ring is bent is equal to or smaller than a maximum inner circumference total stress obtained by adding up a contact stress induced in a part contiguous with the inner circumference of the innermost thin metal ring in contact with an edge of the block, a stress induced in the part contiguous with the inner circumference of the innermost thin metal ring and a bending stress induced in the part contiguous with the inner circumference of the innermost thin metal ring.

Claims

1. Thin metal rings for a nonstep variable-speed transmission having a drive pulley and a driven pulley, the respective effective diameters of the drive and the driven pulley being variable to change speed change ratio, said thin metal

rings being layered to form layered ring structures, a plurality of blocks being arranged along and supported on the layered ring structures to form an endless metal belt, and the endless metal belt being extended between the drive and the driven pulley;

wherein a radially inner edge at an intersection of an outer side surface and an inner circumference of an innermost thin metal ring among the thin metal rings, that will come into contact with a side surface of a pulley groove of the drive pulley and a side surface of a pulley groove of the driven pulley is rounded in a round edge of a radius R of curvature, and the radius R of curvature is determined so that a maximum total round edge stress obtained by adding up a contact stress induced in the round edge of the innermost thin metal ring in contact with the side surface of the pulley groove, a stress induced in the round edge by a tensile force exerted on the innermost thin metal ring, and a bending stress induced in the round edge of the innermost thin metal ring when the innermost thin metal ring is bent is equal to or smaller than a maximum inner circumference total stress obtained by adding up a contact stress induced in a part contiguous with the inner circumference of the innermost thin metal ring in contact with an edge of the block, a stress induced in the part contiguous with the inner circumference of the innermost thin metal ring and a bending stress induced in the part contiguous with the inner circumference of the innermost thin metal ring.

2. Thin metal rings for a nonstep variable-speed transmission having a drive pulley and a driven pulley, the respective effective diameters of the drive and the driven pulley being variable to change speed change ratio, said thin metal rings being layered to form layered ring structures, a plurality of blocks being arranged along and supported on the layered ring structures to form an endless metal belt, and the endless metal belt being extended between the drive and the driven pulley;

wherein an edge at the intersection of an outer side surface and an inner circumference of an innermost thin metal ring among the thin metal rings, that will come into contact with a side surface of a pulley groove of the drive pulley and a side surface of a pulley groove of the driven pulley is rounded in a round edge of a radius R of curvature, and the radius R of curvature is determined so that a round edge stress difference between a maximum and a minimum total round edge stress obtained by adding up a contact stress induced in the round edge of the innermost thin metal ring in contact with the side surface of the pulley groove, a stress induced in the round edge by a tensile force exerted on the innermost thin metal ring, and a bending stress induced in the round edge of the innermost thin metal ring when the innermost thin metal ring is bent is smaller than an inner circumference stress difference between a maximum and a minimum inner circumference total stress obtained by adding up a contact stress induced in a part contiguous with the inner circumference of the innermost thin metal ring in contact with an edge of the block, a stress induced in the part contiguous with the inner circumference of the innermost thin metal ring and a bending stress induced in the part contiguous with the inner circumference of the innermost thin metal ring when the innermost thin metal ring is bent.

3. Thin metal rings for a nonstep variable-speed transmission having a drive pulley and a driven pulley, the respective effective diameters of the drive and the driven pulley being variable to change speed change ratio, said thin metal rings being layered to form layered ring structures, a plurality of blocks being arranged along and supported on the layered ring structures to form an endless metal belt, and the endless metal belt being extended between the drive and the driven pulley;

wherein an edge at the intersection of an outer side surface and an inner circumference of an innermost thin metal ring among the thin metal rings, that will come into contact with the side surface of the pulley groove of the drive pulley and the side surface of the pulley groove of the driven pulley is rounded in a round edge of a radius R of curvature, and the radius R of curvature is determined so that a round edge fatigue stress determined from a maximum and a minimum total round edge stress obtained by adding up a contact stress induced in the round edge of the innermost thin metal ring in contact with the side surface of the pulley groove, a stress induced in the round edge by a tensile force exerted on the innermost thin metal ring, and a bending stress induced in the round edge of the innermost thin metal ring when the innermost thin metal ring is bent is equal to or smaller than an inner circumference fatigue stress determined from a maximum and a minimum inner circumference total stress obtained by adding up a contact stress induced in a part contiguous with the inner circumference of the innermost thin metal ring in contact with an edge of the block, a stress induced in the part contiguous with the inner circumference of the innermost thin metal ring and a bending stress induced in the part contiguous with the inner circumference of the innermost thin metal ring.

4. Thin metal rings for a nonstep variable-speed transmission having a drive pulley and a driven pulley, the respective effective diameters of the drive and the driven pulley being variable to change speed change ratio, said thin metal rings being layered to form layered ring structures, a plurality of blocks being arranged along and supported on the layered ring structures to form an endless metal belt, and the endless metal belt being extended between the drive

and the driven pulley;

wherein an edge at an intersection of an outer side surface and an inner circumference of an innermost thin metal ring among the thin metal rings, that will come into contact with a side surface of a pulley groove of the drive pulley and a side surface of a pulley groove of the driven pulley is rounded in a round edge of a radius R of curvature, and the radius R of curvature is determined so that a contact part corrected stress difference ($\sigma_{a*HP} = \sigma_{aHP} + \sigma_{mHP}/3$) calculated by adding a round edge stress difference σ_{aHP} between a maximum and a minimum total round edge stress obtained by adding up a contact stress induced in the round edge of the innermost thin metal ring in contact with the side surface of the pulley groove, a stress induced in the round edge by a tensile force exerted on the innermost thin metal ring, and a bending stress induced in the round edge of the innermost thin metal ring when the innermost thin metal ring is bent, and 1/3 of a mean round edge stress (σ_{mHP}) equal to the mean of the maximum and the minimum total round edge stress is equal to or smaller than an inner circumference corrected stress difference ($\sigma_{a*} = \sigma_a + \sigma_m/3$) calculated by adding an inner circumference stress difference (σ_a) between a maximum and a minimum inner circumference total stress obtained by adding up a contact stress induced in a part contiguous with the inner circumference of the innermost thin metal ring in contact with an edge of the block, a stress induced in the part contiguous with the inner circumference of the innermost thin metal ring and a bending stress induced in the part contiguous with the inner circumference of the innermost thin metal ring when the innermost thin metal ring is bent, and 1/3 of the mean ($\sigma_m/3$) of the maximum and the minimum inner circumference total stress ($\sigma_{a*HP} \leq \sigma_{a*}$).

5. The thin metal rings according to claim 4, wherein the radius R of curvature of the round edge of the innermost thin metal ring is determined so that a condition:

$$y \geq 1.5379x^4 - 3.8442x^3 + 3.5636x^2 - 1.5713x + 0.3725$$

where $x = h/t$, h is height of a contact part of the side of the innermost thin metal ring that will come into contact with the side surface of the pulley groove from the inner circumference of the innermost thin metal ring, t is thickness of the innermost thin metal ring and $y = R/t$, is satisfied.

6. Thin metal rings for a nonstep variable-speed transmission having a drive pulley and a driven pulley, the respective effective diameters of the drive and the driven pulley being variable to change speed change ratio, said thin metal rings being layered to form layered ring structures, a plurality of blocks being arranged along and supported on the layered ring structures to form an endless metal belt, and the endless metal belt being extended between the drive and the driven pulley;

wherein an edge at an intersection of an outer side surface and an inner circumference of an innermost thin metal ring among the thin metal rings, that will come into contact with a side of a pulley groove of the drive pulley and a side of a pulley groove of the driven pulley is rounded in a round edge of a radius R of curvature having the shape of a quarter of a cylinder, and the radius R is determined so that a contact part corrected stress difference calculated by adding a round edge stress difference between a maximum and a minimum total round edge stress obtained by adding up a contact stress induced in the round edge of the innermost thin metal ring in contact with the side surface of the pulley groove, a stress induced in the round edge by a tensile force exerted on the innermost thin metal ring, and a bending stress induced in the round edge of the innermost thin metal ring when the innermost thin metal ring is bent, and 1/3 of a mean round edge stress equal to the mean of the maximum and the minimum total round edge stress is equal to or smaller than an inner circumference corrected stress difference calculated by adding an inner circumference stress difference between a maximum and a minimum inner circumference total stress obtained by adding up a contact stress induced in the part contiguous with the inner circumference of the innermost thin metal ring in contact with an edge of the block, a stress induced in the part contiguous with the inner circumference of the innermost thin metal ring and a bending stress induced in the part contiguous with the inner circumference of the innermost thin metal ring when the innermost thin metal ring is bent, and 1/3 of the mean of the maximum and the minimum inner circumference total stress. Thus, the failure of the round edge of the innermost thin metal ring that will come into contact with the side surface of the pulley groove due to fatigue stress can be prevented and the durability and reliability of the innermost thin metal ring can be greatly improved.

7. Thin metal rings for a nonstep variable-speed transmission having a drive pulley and a driven pulley, the respective effective diameters of the drive and the driven pulley being variable to change speed change ratio, said thin metal rings being layered to form layered ring structures, a plurality of blocks being arranged along and supported on the layered ring structures to form an endless metal belt, and the endless metal belt being extended between the drive and the driven pulley;

wherein an edge at an intersection of an outer side surface and an inner circumference of an innermost thin

metal ring among the thin metal rings, that will come into contact with a side surface of a pulley groove of the drive pulley and a side surface of a pulley groove of the driven pulley is chamfered in a bevel surface at an angle greater than an groove angle (α) of the pulley groove and the bevel surface is merged smoothly into the outer side surface of the innermost thin metal ring by a round edge of a radius R of curvature that comes into contact with the side surface of the pulley groove, and the radius R is determined so that a contact part corrected stress difference calculated by adding a round edge stress difference between a maximum and a minimum total round edge stress obtained by adding up a contact stress induced in the round edge of the innermost thin metal ring in contact with the side surface of the pulley groove, a stress induced in the round edge by a tensile force exerted on the innermost thin metal ring, and a bending stress induced in the round edge of the innermost thin metal ring when the innermost thin metal ring is bent, and $1/3$ of a mean round edge stress equal to the mean of the maximum and the minimum total round edge stress is equal to or smaller than an inner circumference corrected stress difference calculated by adding an inner circumference stress difference between a maximum and a minimum inner circumference total stress obtained by adding up a contact stress induced in the part contiguous with the inner circumference of the innermost thin metal ring in contact with an edge of the block, a stress induced in the part contiguous with the inner circumference of the innermost thin metal ring and a bending stress induced in the part contiguous with the inner circumference of the innermost thin metal ring when the innermost thin metal ring is bent, and $1/3$ of the mean of the maximum and the minimum inner circumference total stress.

8. Thin metal rings for a nonstep variable-speed transmission having a drive pulley and a driven pulley, the respective effective diameters of the drive and the driven pulley being variable to change speed change ratio, said thin metal rings being layered to form layered ring structures, a plurality of blocks being arranged along and supported on the layered ring structures to form an endless metal belt, and the endless metal belt being extended between the drive and the driven pulley;

wherein a side surface of each thin metal ring has a middle flat part, an edge at the intersection of the side surface and an inner circumference of the thin metal ring is rounded in a round edge of a radius R_1 of curvature and an edge at the intersection of the side surface and an outer circumference of the thin metal ring is rounded in a round edge of a radius R_2 of curvature different from the radius R_1 .

9. Thin metal rings for a nonstep variable-speed transmission having a drive pulley and a driven pulley, the respective effective diameters of the drive and the driven pulley being variable to change speed change ratio, said thin metal rings being layered to form layered ring structures, a plurality of blocks being arranged along and supported on the layered ring structures to form an endless metal belt, and the endless metal belt being extended between the drive and the driven pulley;

wherein a side surface of each thin metal ring has a middle flat part, an edge at the intersection of the side surface and an inner circumference of the thin metal ring is rounded in a radially inner round edge of a radius R_1 of curvature and an edge at the intersection of the side surface and an outer circumference of the thin metal ring is rounded in a radially outer round edge of a radius R_2 of curvature different from the radius R_1 , the radius R_1 of curvature of the radially inner round edge of the thin metal ring meets a condition:

$R_1/t \geq 2/9$, where t is the thickness of the thin metal ring, when the groove angle (α) of the pulley groove is in the range of 6° to 11° .

10. Thin metal rings for a nonstep variable-speed transmission having a drive pulley and a driven pulley, the respective effective diameters of the drive and the driven pulley being variable to change speed change ratio, said thin metal rings being layered to form layered ring structures, a plurality of blocks being arranged along and supported on the layered ring structures to form an endless metal belt, and the endless metal belt being extended between the drive and the driven pulley;

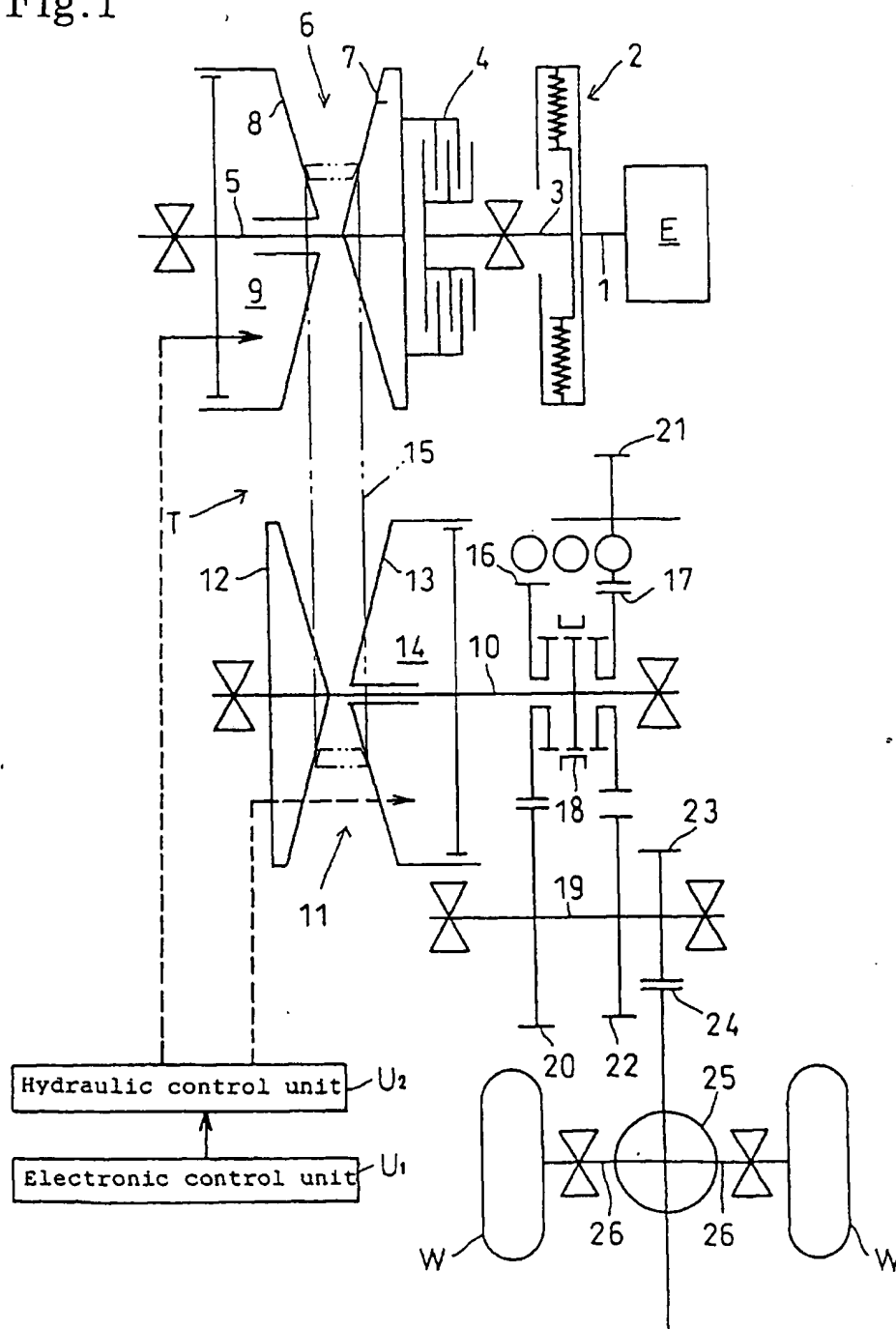
wherein a side surface of each thin metal ring has a middle flat part, an edge at the intersection of the side surface and an inner circumference of the thin metal ring is rounded in a radially inner round edge of a radius R_1 of curvature and an edge at the intersection of the side surface and an outer circumference of the thin metal ring is rounded in a radially outer round edge of a radius R_2 of curvature different from the radius R_1 , the radius R_1 of curvature of the radially inner round edge of each thin metal ring is greater than the radius R_2 of curvature of the radially outer round edge of the same thin metal ring.

11. Thin metal rings for a nonstep variable-speed transmission having a drive pulley and a driven pulley, the respective effective diameters of the drive and the driven pulley being variable to change speed change ratio, said thin metal rings being layered to form layered ring structures, a plurality of blocks being arranged along and supported on the layered ring structures to form an endless metal belt, and the endless metal belt being extended between the drive and the driven pulley;

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wherein a side surface of each thin metal ring has a middle flat part, an edge at the intersection of the side surface and an inner circumference of the thin metal ring is rounded in a radially inner round edge of a radius R_1 of curvature and an edge at the intersection of the side surface and an outer circumference of the thin metal ring is rounded in a radially outer round edge of a radius R_2 of curvature different from the radius R_1 , respective radii R_1' and R_2' of curvature of the radially inner and the radially outer round edge of the innermost thin metal ring are equal to or greater than the respective radii R_1 and R_2 of curvature of the radially inner and the radially outer round edge of the thin metal rings other than the innermost thin metal ring, respectively.

Fig.1



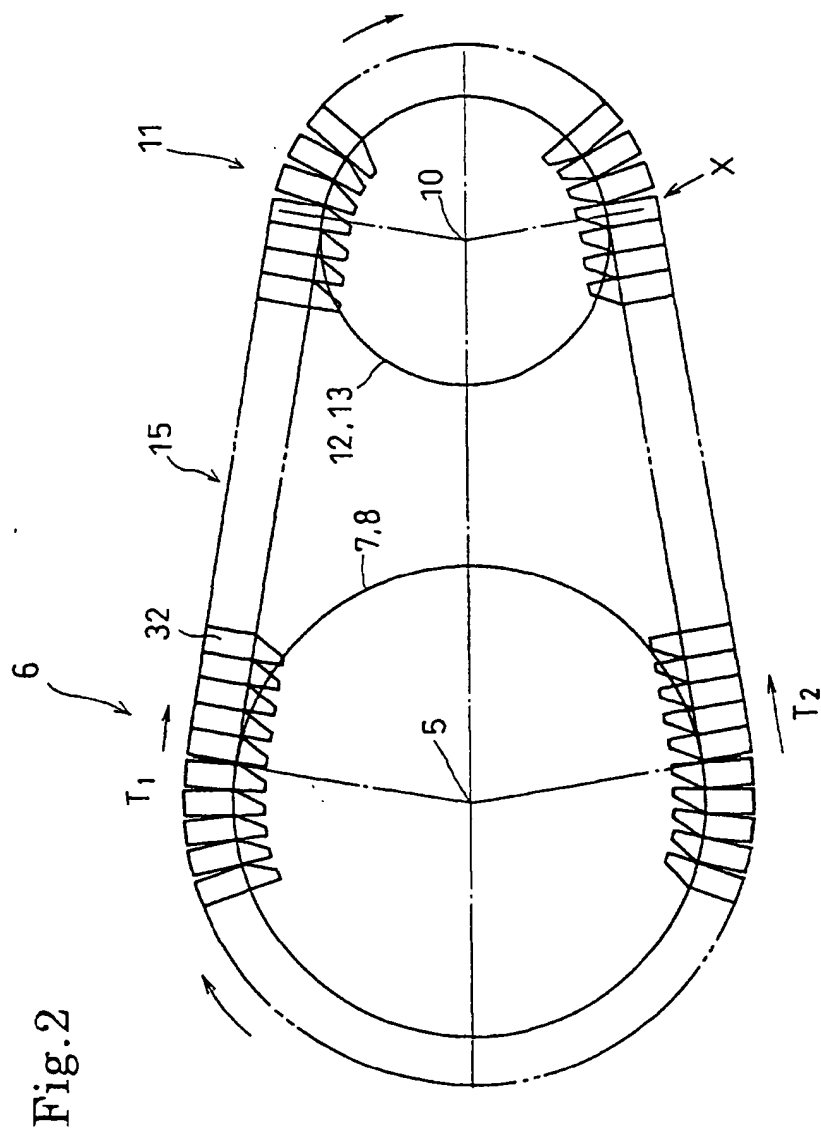


Fig. 2

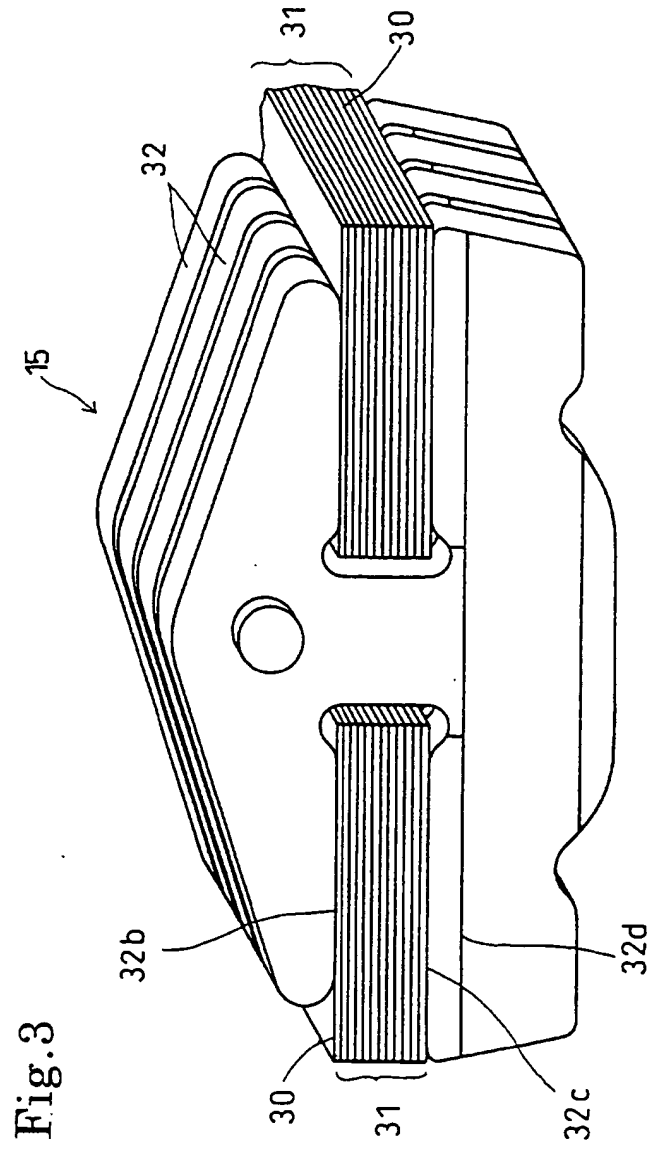


Fig. 3

Fig.4

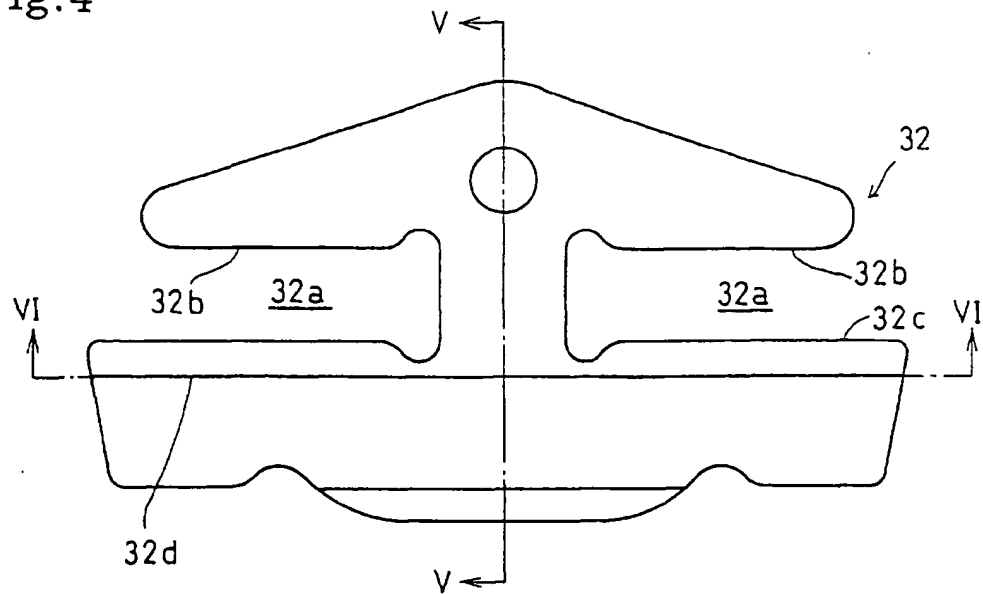


Fig.5

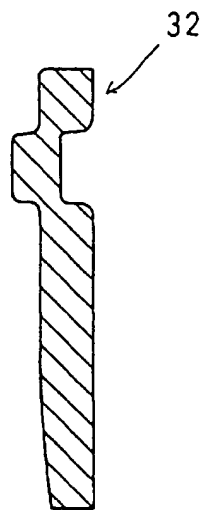


Fig.6

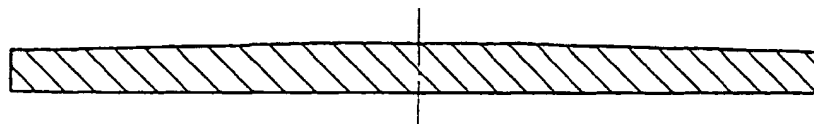


Fig.7

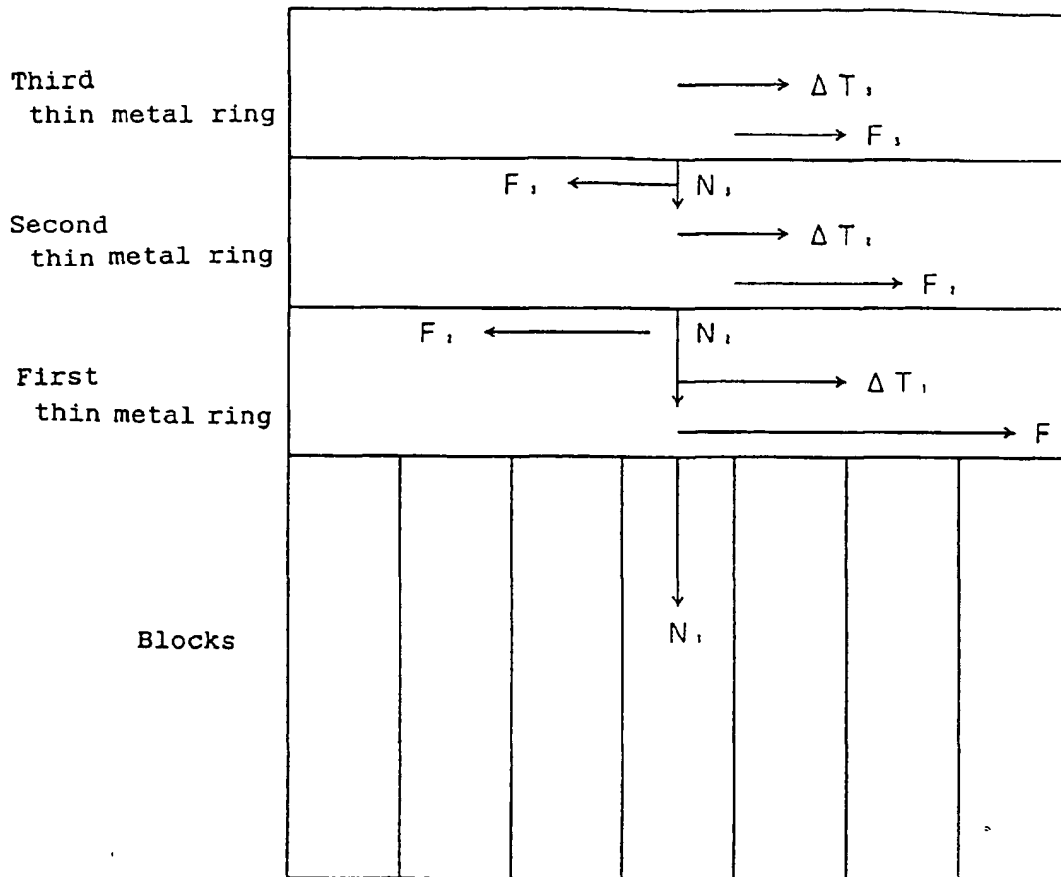


Fig.8

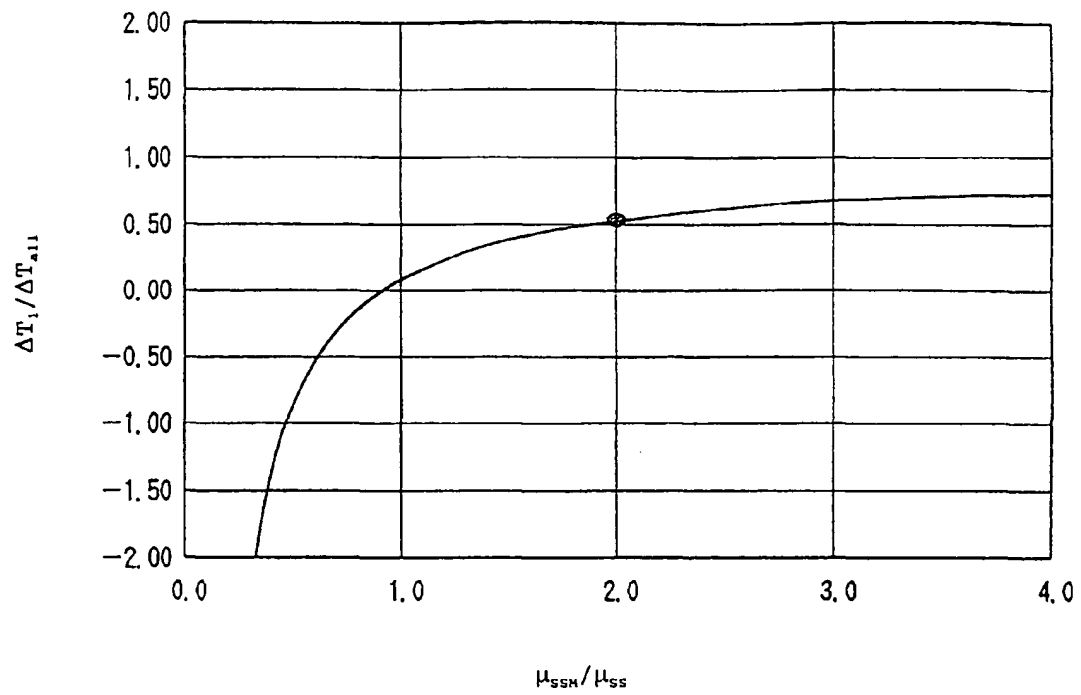


Fig.9

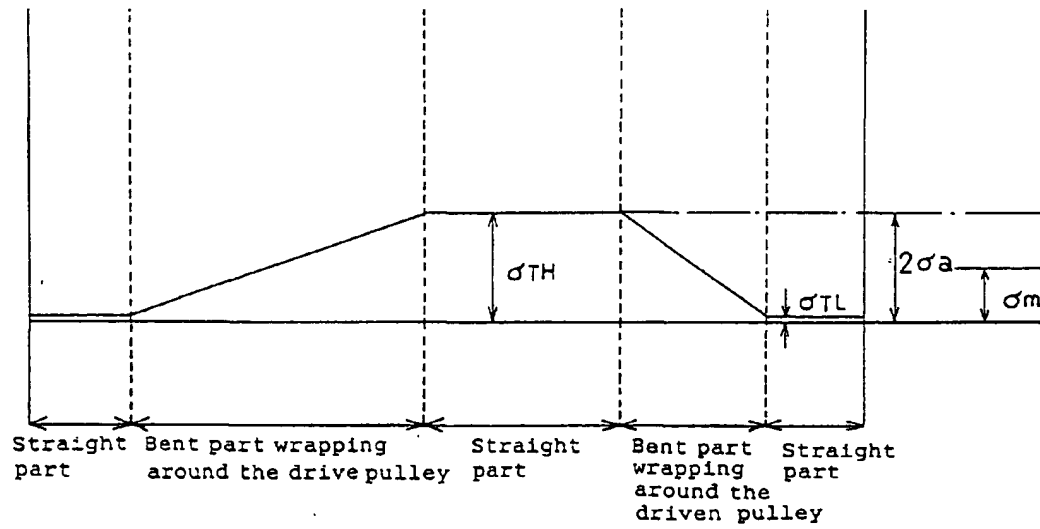


Fig.10

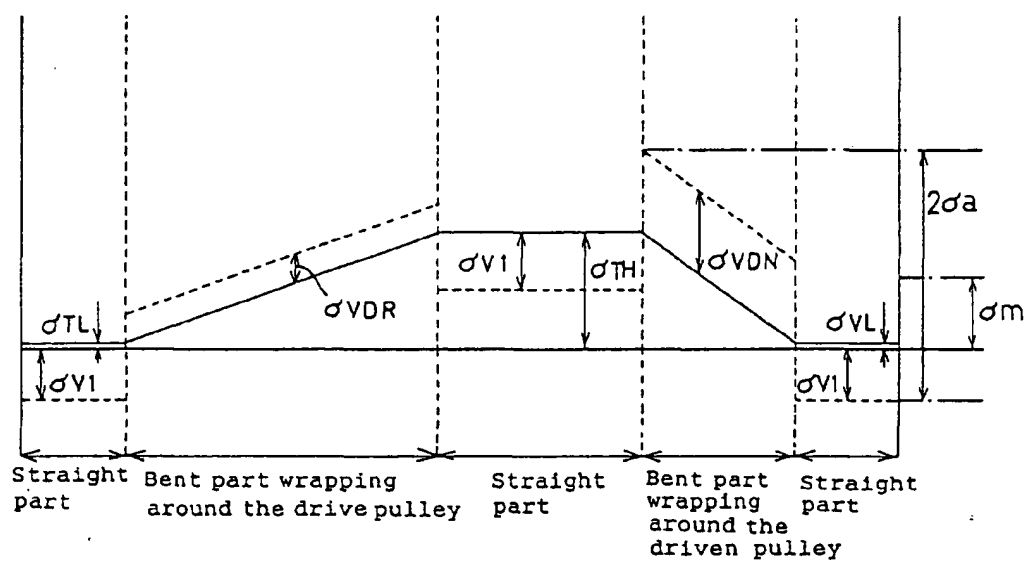


Fig.11

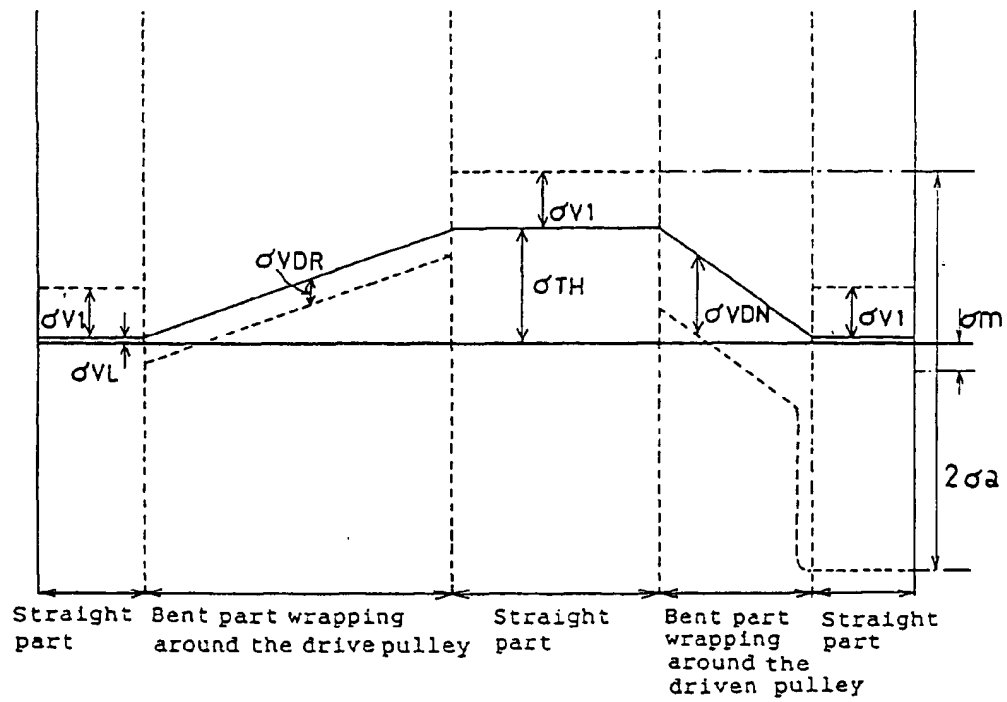


Fig.12

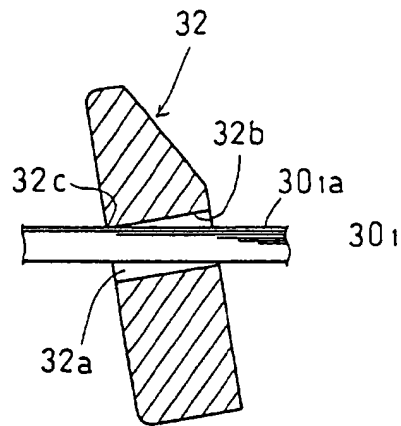


Fig.13

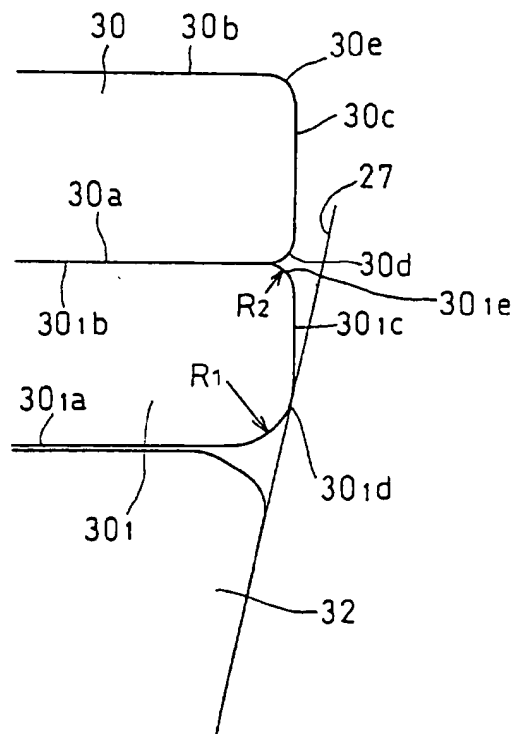


Fig.14

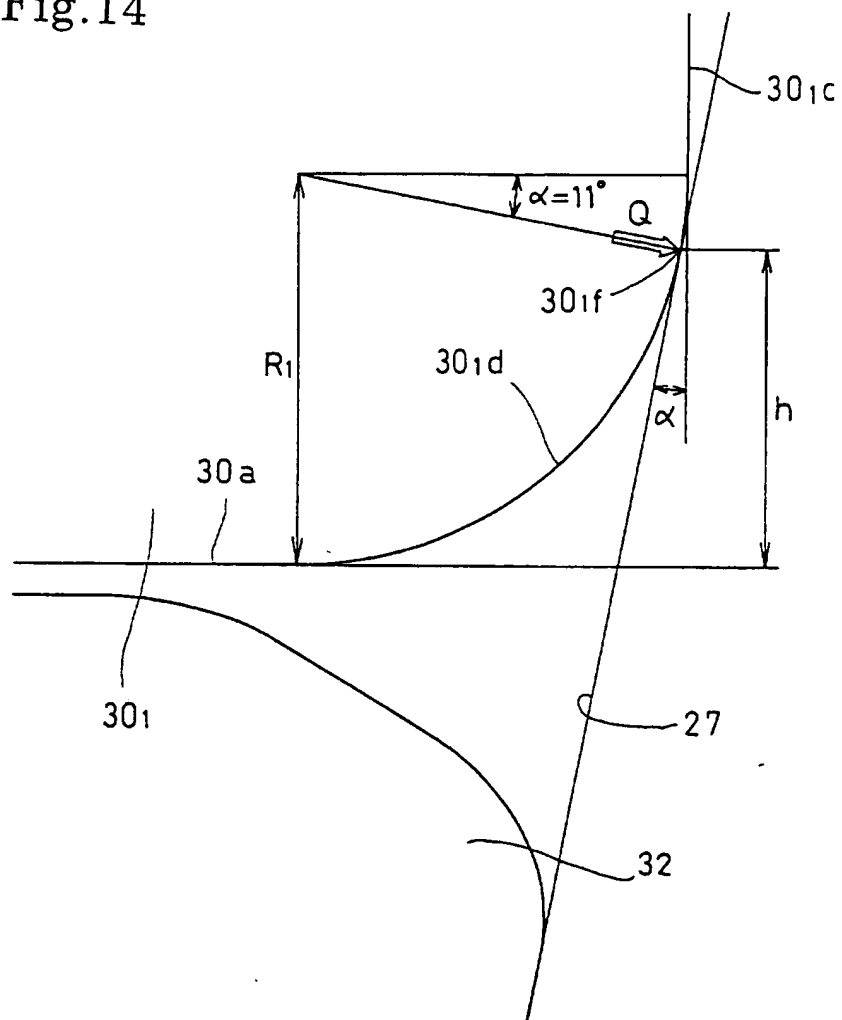
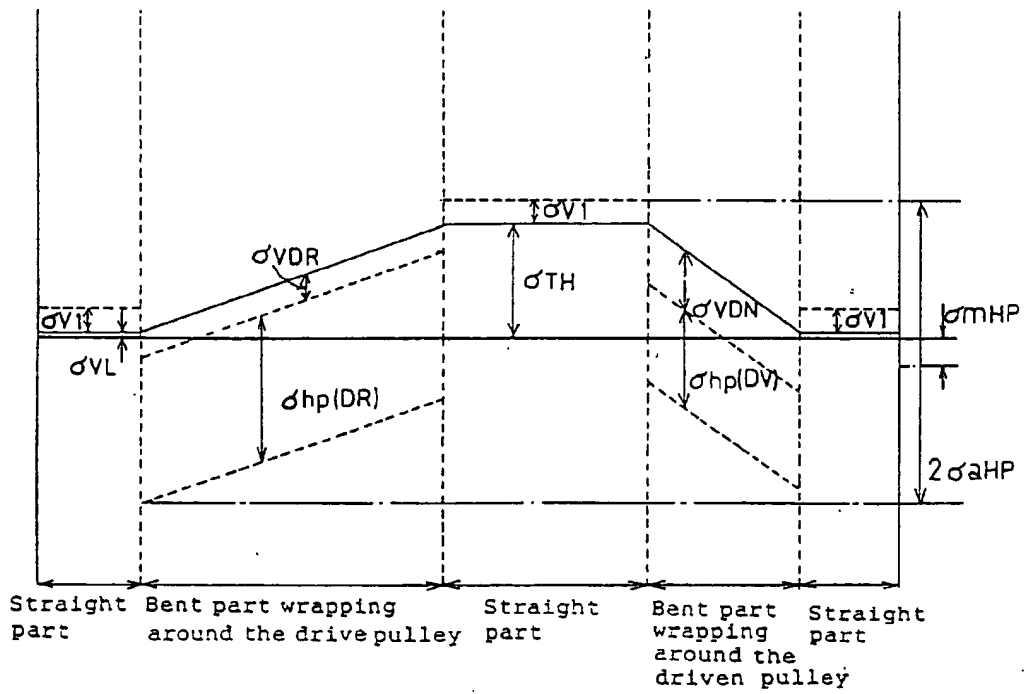


Fig.15



Corrected stress differences relating to the interior
and the end of the innermost thin metal ring

Contact ratio: 100% (Pulley side)

Fig.16

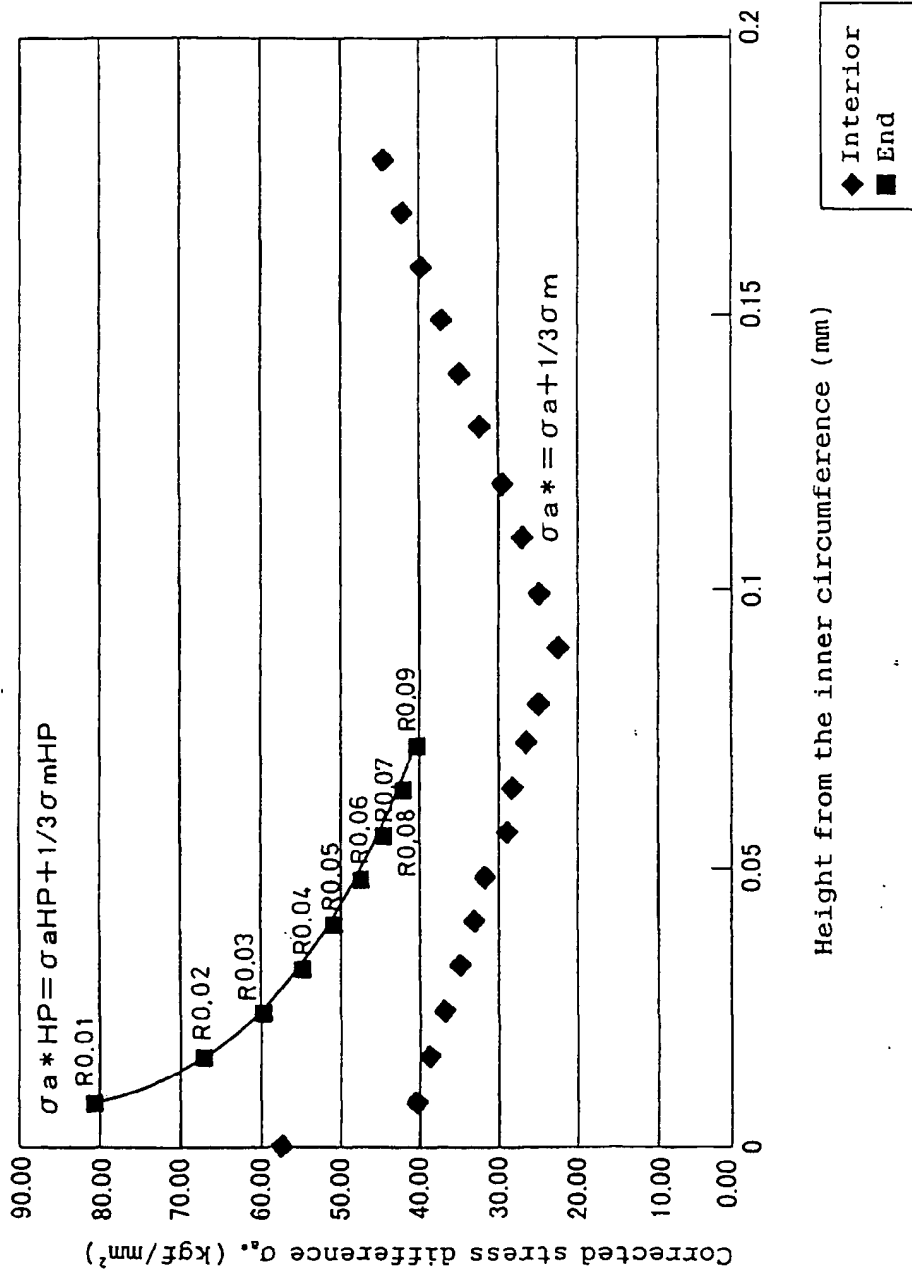


Fig.17

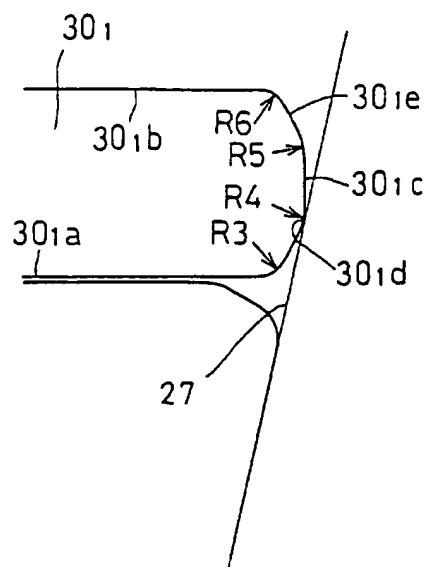


Fig.18

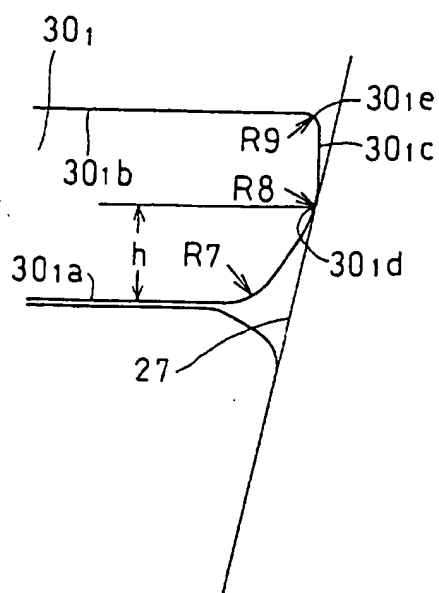


Fig.19

Groove angle (degree)	Radius R	Height h	Pulley Hertz compressive stress		Internal stress (Innermost thin metal ring)			Contact part stress (Innermost thin metal ring)		
			$\sigma_{hp}(DR)$	$\sigma_{hp}(DN)$	σ_a	σ_m	σ_{at}	σ_{aHP}	σ_{mHP}	σ_{atHP}
11	0	0			60	-8	57.33			
11	0.01	0.0081	134.2	120.6	35.4	15.1	40.43	95.7	-45.2	80.63
11	0.02	0.0162	94.9	85.3	33.6	15.4	38.73	76.2	-27.2	67.13
11	0.03	0.0243	77.5	69.6	31.6	15.7	36.83	66.4	-19.1	60.03
11	0.04	0.0324	67.1	60.3	29.8	16.1	35.17	59.9	-14.1	55.20
11	0.05	0.0405	60	53.9	27.9	16.4	33.37	54.9	-10.6	51.37
11	0.06	0.0486	54.8	49.2	26.1	16.7	31.67	50.7	-7.9	48.07
11	0.07	0.0567	50.7	45.6	23.1	17.2	28.83	47.1	-5.8	45.17
11	0.08	0.0647	47.5	42.6	22.4	17.3	28.17	43.9	-4.2	42.50
11	0.09	0.0728	44.8	40.2	20.5	17.6	26.37	41.4	-3.3	40.30
		0.08			18.9	17.9	24.87			
		0.09			16.6	18.3	22.70			
		0.1			18.9	18.7	25.13			
		0.11			21.1	19.1	27.47			
		0.12			23.5	19.5	30.00			
		0.13			25.8	19.9	32.43			
		0.14			28.1	20.3	34.87			
		0.15			30.3	20.7	37.20			
		0.16			32.6	21.2	39.67			
		0.17			34.9	21.4	42.03			
		0.18			37.2	21.8	44.47			

Fig.20

$$\sigma a^*HN + 1/3 \sigma m + 1/3 \sigma aH$$

Total contact load on DR: 12.7 kgf Length of wrap on DR: 234.2 mm

 $h = 0 \text{ to } 0.04$

$$\sigma aH = 3 \sigma a^*HN - 3 \sigma a - \sigma m$$

Total contact load on DN: 5.1 kgf Length of wrap on DN: 116.6 mm

Radius R of curvature	Height h	Contact part Hertz compressive stress		Internal stress in the innermost thin metal ring			Neck contact part stress in the innermost thin metal ring			Ratio y (R/t)	Ratio x (h/t)
		σ hP (DR)	σ hP (DN)	σa	σm	σa^*	σaHP	σmHP	σa^*HP		
	0			60	-8	57.33					0.00
0.0536	0.01	58	52.09	34.9	15.2	39.97	61	-10.9	57.33	0.30	0.06
0.0424	0.02	65.2	58.59	32.6	15.6	37.80	61.9	-13.7	57.33	0.24	0.11
0.0343	0.03	72.5	65.09	30.3	16	35.63	62.9	-16.6	57.33	0.19	0.17
0.0285	0.04	79.5	71.39	28.1	16.3	33.53	63.8	-19.4	57.33	0.18	0.22
0.025	0.05	85	76.3	25.8	16.7	31.37	64.7	-22.2	57.33	0.14	0.28
0.0223	0.06	89.7	80.7	23.5	17.1	29.20	65.7	-25.1	57.33	0.12	0.33
0.0202	0.07	94.5	84.8	21.2	17.5	27.03	66.6	-27.9	57.33	0.11	0.39
0.0184	0.08	99	88.9	18.9	17.9	24.87	67.6	-30.8	57.33	0.10	0.44
0.0167	0.09	103.89	93.3	16.9	18.3	22.60	68.5	-33.6	57.33	0.09	0.50
0.0153	0.1	108.8	97.5	18.9	18.7	25.13	69.5	-36.5	57.33	0.09	0.56
0.014	0.11	113.4	101.9	21.1	19.1	27.47	70.5	-39.4	57.33	0.08	0.61
0.0129	0.12	118.1	106.2	23.5	19.5	30.00	71.4	-42.2	57.33	0.07	0.67
0.0119	0.13	122.8	110.5	25.8	19.9	32.43	72.3	-45	57.33	0.07	0.72
0.0111	0.14	127.5	114.4	28.1	20.3	34.87	73.3	-47.9	57.33	0.06	0.78
0.0103	0.15	132.3	118.8	20.3	20.7	37.20	74.3	-50.8	57.33	0.06	0.83
0.0096	0.16	137	123.1	32.6	21.2	39.67	75.2	-53.6	57.33	0.05	0.89
0.009	0.17	141.7	127.1	34.9	21.4	42.03	76.1	-56.4	57.33	0.05	0.94
0	0.18			37.2	21.8	44.47				0.00	1.00

Fig.21

Relation between the height from the inner circumference
and the radius of curvature of the round edge

